RESECTION OF THE PYLORUS—ITS EFFECT ON THE SECRETORY AND MOTOR FUNCTIONS OF THE STOMACH*†

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SURGERY steadily is assuming greater importance in the treatment of disease of the stomach and duodenum, owing to the appearance of increasing numbers of reports of favorable clinical results. In clinical practice three general types of surgical operation are employed in the treatment of disease of these organs, namely, plastic gastroduodenostomy, simple gastrojejunostomy, and pyloric resection. Resection of the pylorus is employed universally as an operation of necessity for radical cure of malignant disease of the stomach. Opinion is divided, however, regarding the use of this operation in the treatment of benign peptic ulcer. Whereas a small number of gastric surgeons apply it empirically in the treatment of uncomplicated peptic ulcer, another group of surgeons maintain that neither theoretical nor practical results warrant the use of so radical a procedure in the treatment of benign disease. This difference of opinion exists because the physiologic effects of pyloric resection have not been established conclusively.

The problems which arise in an analysis of the fundamental aspects of this subject are numerous and complex. For example, the pyloric portion of the stomach anatomically consists of two parts, the pyloric antrum and the pyloric sphincter. Each of these parts possesses two distinct functions. The functions of the pyloric sphincter are, first, the control of the discharge of food from the stomach, and second, the regulation of the entrance of intestinal juices into the stomach. The functions of the pyloric antrum include, first, the secretion of an alkaline, mucous, non-proteolytic juice, and second, perhaps, the exercise of a subtle influence over the secretory function of the fundus. In an experimental study of the effects of pyloric resection on the physiology of the stomach, one encounters peculiar conditions which must be controlled carefully. As an illustration, there are three phases of gastric secretion: cephalic, gastric, and intestinal. The normal gastric secretory response to ingested food is the composite result of influences from these three sources. Moreover, there occur variations in gastric secretion which are normal. There are secretory variations not only among different individuals, but also within the same individual; hence the necessity of maintaining properly controlled experimental conditions. Inasmuch as the application of operative procedures to the human stomach presupposes the existence of organic disease of the digestive tract, clinical observations are not suitably controlled for physiologic interpretation. A corollary to this is that properly controlled physiologic observations may be made only upon stomachs in which disease does not exist. Thus, in this particular field, clinical results are not necessarily the equivalent of physiologic results. In view of the prevailing conflict of opinion regarding these fundamental and practical problems, an experimental study of the effect of resection of the pylorus on the physiology of the stomach seemed to hold promise.

The study reported here was conducted upon dogs. It is believed that the method which was used adequately controlled the variable factors involved. For example, in order to eliminate and thus control the factor of normal variation of gastric secretory response to a standard stimulus applied to different individuals, multiple operations (as many as five) were performed upon each animal employed. The physiologic effects of each operation were observed after the animal had recovered, by means of the fractional method of gastric analysis, and by roentgenologic examination performed before and repeated four weeks after operation. In this study a total of 22,074 determinations of acidity, including titrable total and free hydrochloric acid and hydrogen ion concentration were made on gastric content. Several different types of operation were utilized to elucidate different phases of the physiologic effects of resection of the pylorus. Multiple resections of graduated, successively greater portions of the pylorus were performed as separate operations, and the effects of each grade of resection were observed in the same animal. Continuity was reëstablished after each resection by means of the Billroth gastroduodenostomy, or by the Polya or Billroth types of gastrojejunostomy. In supplementary studies the Pavlov fundus pouch, the Roux jejunojejunostomy, and bilateral transthoracic vagotomy were utilized. The effect of using one-half the amount of the test-meal also was observed. In keeping with the fundamental anatomic and physiologic character of these studies, descriptive historico-anatomic rather than strictly surgical nomenclature has been applied to the operations used. The results of these studies are of apparent physiologic, surgical, and clinical significance.

LITERATURE

Because of the limited space available, none of the three hundred articles in the literature on this subject, which were reviewed, will be referred to here, except by stating that the impression prevails among physicians that either resection of the pylorus or anastomosis between the stomach and intestine are sufficient in themselves to reduce the acidity of gastric content.

PROCEDURE

Throughout these studies on the effects of resection of the pylorus on the physiology of the stomach, a standard procedure was used. The

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experiments were conducted upon healthy dogs of uniform medium weight.

The effects of operation on both secretory and motor functions of the stomach were noted. The effects on gastric secretion were observed by fractional analysis of gastric content. The effects on the motility of the stomach were observed roentgenologically. Repeated observations were made before operation and again at a uniform interval of four weeks after recovery from operation. A standard test-meal, consisting of 80 grams of fresh, lean, ground meat, and 250 cubic centimeters of tap water, and a standard dose of 1.0 milligram of histamin in fresh solution were employed separately as gastric secretory stimulants. A standard opaque meal of barium sulphate in gum acacia solution was utilized in roentgenologic examination. During the course of digestion, portions of gastric content were withdrawn from the stomach by negative pressure through a Smithies stomach tube. The emptying rate of the stomach was observed fluoroscopically following the administration of the opaque meal. On each sample of gastric content three determinations of acidity were made. Total and free hydrochloric acid were determined by the usual clinical method of titration of gastric content. Hydrogen ion concentration was determined potentiometrically.

Special care was exercised in the control of the normal variations in gastric secretion. The factor of normal temporal variation, within each individual, of gastric secretory response to a constant stimulus was controlled in three ways: first, by thoroughly training each animal to the routine of gastric analysis so that psychic influences were eliminated; second, by performing fractional analysis of the continuous (basal, resting) secretion at regular intervals over periods as long as one hour before the secretory stimulus was applied; and third, by drawing conclusions only on an agreement of the results of fractional analysis performed in triplicate before, as well as after, each operation. The factor of natural variation, among different individuals, of gastric secretory response to a given stimulus was controlled in two ways: first, by the performance of multiple operations on the same animal; and second, by the performance of the same operation on more than one animal. Obviously it is not possible to control these conditions in an analysis of the results of the operations which are performed on man.

This study of the physiologic effects of resection of the pylorus was conducted in three phases. The first phase consisted of observing only the gross effects of resection on the acidity and movement of gastric content. Observations in the second phase were limited to the effects of pyloric resection on the secretory function of the stomach. The third phase was confined to observations on the neutralization of gastric juice after it is secreted into the pylorectomized stomach. Appropriate surgical methods were employed in each phase of the investigation.

In the first phase, the gross effects of resection of the pylorus were analyzed in detail by a method

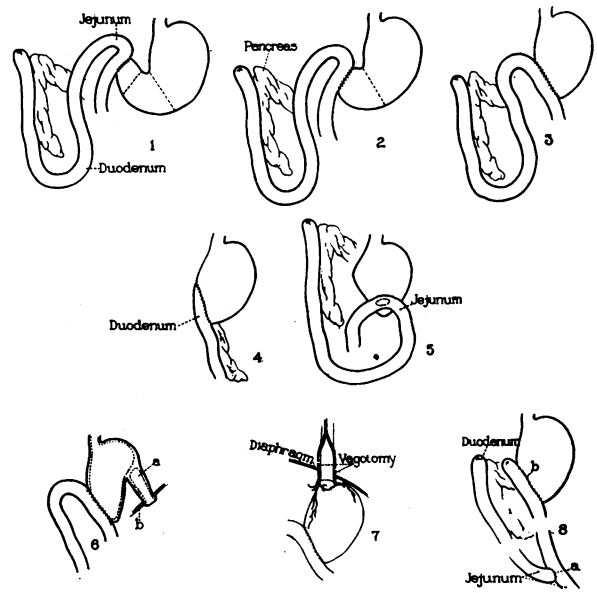

Fig. 1.—Diagrams of the operations which were used in the study of the effects of resection of the pylorus on the secretory and motor functions of the stomach: 1. Grade 1 resection of the pylorus with Polya gastrojejunostomy. 2. Grade 2 resection of the pylorus. 3. Grade 3 resection of the pylorus. 4. Pyloric resection with Billroth I gastroduodenostomy. 5. Pyloric resection with Billroth II gastrojejunostomy. 6. The Pavlov pouch in the pylorectomized stomach: (a) Pavlov pouch; (b) Abdominal wall. 7. Bilateral supradiaphragmatic vagotomy in the pylorectomized stomach. 8. The Roux jejunojejunostomy in the pylorectomized stomach.

which I devised especially for this study. The procedure permits investigation of the distinct functions of the two portions of the pylorus separately. This method consists of performing multiple graduated resections of the pylorus on the same animal. Resection graded 1 comprises removal of the distal one centimeter of the circumference of the pyloric portion of the stomach, including the pyloric sphincter (Fig. 1; 1). Keeping in mind the dual function of the pyloric sphincter, the effects of its removal should be reflected in two ways: first, by alterations in the motility (emptying) of the stomach; and second, by alterations in the acidity of gastric content resulting from more ready entrance of duodenal juices into the stomach. Recalling also the two functions of the pyloric antrum, these were observed quantitatively by the process of removing the distal and proximal halves of the antrum at separate operations. To accomplish this, two more grades of resection are employed. In resection graded 2, the distal half of the remainder of the pylorus is removed (Fig. 1; 2). Resection graded 3 consists of excision of the remaining half of the pylorus, along with a narrow band of the distal portion of the fundus in order to insure removal of all of the pyloric mucosa (Fig. 1; 3). Being the simplest of the standard methods of performing gastrointestinal anastomosis after resection of the pylorus, the Polya gastrojejunostomy is used. The observations on resection of the pylorus were conducted on ten dogs. Upon each dog multiple graduated resections were performed as described.

For the purpose of comparing other standard forms of anastomosis between the pylorectomized stomach and the intestine, the Billroth I gastroduodenostomy and the Billroth II gastrojejunostomy each were performed on pylorectomized dogs (Fig. 1; 4 and 5, respectively). Two dogs were used for each form of anastomosis. Thus, in the first phase of this study, only standard operative procedures which are used in clinical surgery were employed. Accordingly this phase corresponds to the clinical investigations which have been conducted on man.

In the second phase of the investigation, two additional operative procedures were applied to the stomachs of animals which had been pylorectomized at previous operations, namely, the Pavlov pouch and bilateral supradiaphragmatic vagotomy. These operations cannot be used justifiably in man, but are of the utmost service in the experimental elucidation of the effects of resection of the pylorus on the secretory function of the stomach. The Pavlov pouch was constructed in the fundus of the stomach of each of five dogs which had been used previously in observations on multiple graduated resections of the pylorus (Fig. 1; 6). Following ingestion of the test-meal, it was possible to collect from these isolated portions of the stomach pure fundus secretion. The acidity of the pure secretion was compared with that of the food and gastric juice mixture which was removed simultaneously from the stomach. The second operation used in this phase of the investigation was performed on three pylorectomized dogs. According to the Pavlov school, which recognizes gastric (secretogogue) and cephalic (psychic) phases of gastric secretion, the former phase is removed by excision of the pylorus, but the latter phase is not affected by this operation. By means of supradiaphragmatic bilateral vagotomy, it is possible to eliminate the cephalic phase of gastric secretion in the pylorectomized stomach and thus determine its rôle in the residual secretory function of the stomach (Fig. 1; 7). The actual state of gastric secretory function in the pylorectomized stomach was determined by the aid of these two special operations.

For the purpose of investigating the neutralization of gastric juice which is secreted into the pylorectomized stomach as the third phase of the present study, two procedures were used. In the first procedure, the rôle which the duodenal juices play in this respect was observed by utilizing the Roux jejunojejunostomy. This operation was performed on three pylorectomized dogs. By means of this surgical procedure, the duodenal juices were shunted into the jejunum at a level forty-eight centimeters distal to the original Polya gastrojejunal anastomosis (Fig. 1; 8). In this manner their neutralizing effects were excluded from the stomach. In the second procedure of this phase of this investigation, the effects of different quantities of food on the acid values of the content of the pylorectomized stomach were observed. This was accomplished by comparing the results obtained from the use of the standard meal with those secured from the use of a meal containing one-half the standard quantity of ingredients. Two dogs were used in these observations. The effect of resection of the pylorus on neutralization of gastric content was observed by these methods.

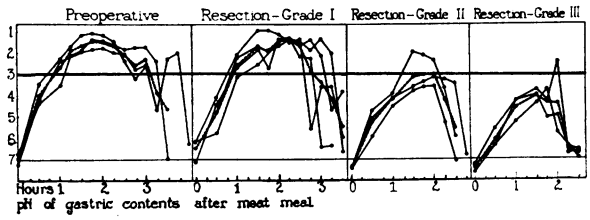

Fig. 2.—Chart illustrating the effect of graduated multiple resection of the pylorus on the hydrogen ion concentration of the gastric content according to repeated fractional gastric analysis, employing the standard test-meal of meat and water. Note that the concentration of H ions is not lowered after resection grade 1, that it is slightly lowered after resection grade 2, that after grade 3 resection it is markedly lowered, and that free hydrochloric acid is not present (H ions below 3).

RESULTS OF EXPERIMENTS

In the succeeding report on the observed effects of resection of the pylorus, the term "acid values of gastric content" refers collectively to hydrogen ion concentration and titrable total and free acids. Likewise, the term "duodenal juices" refers to the mixture of succus entericus, pancreatic juice, and bile, as it occurs in the duodenum during digestion. In the figures which illustrate this report, the variations in H ion concentration observed in gastric analysis performed in triplicate are shown. They are plotted in terms of pH.* The pH curves formed in this way are inverted, so as to conform with the direction taken by the curves which are used in clinical practice to represent titrable acidity. Since by definition the symbol pH is the negative expression for H ion concentration, the latter term is retained in this report to compensate for the inversion of the curves. Thus, a rise in the inverted pH curve denotes a decrease in pH and an increase in H ion concentration.

Attention also is called to the line which extends horizontally across each figure from the number 3. In gastric content having a concentration of H ions of 3, a trace of titrable free hydrochloric acid also is present. The portions of the H ion concentration curves which occupy the zone above this line thus indicate the presence also of free hydrochloric acid in the gastric content. Free hydrochloric acid is not present if the curves do not extend to the level of this line. The titrations of free hydrochloric acid which were conducted simultaneously with the H ion concentration determinations actually demonstrated the truth of this relationship.

GRADUATED MULTIPLE RESECTION WITH POLYA GASTROJEJUNOSTOMY

The observations on the gross effects of graduated multiple resections of the pylorus were significant. After these resections the acid values of gastric content subsequent to ingestion of the test-meal varied indirectly with the amount of the pylorus removed (Fig. 2). Like results were observed in the ten animals used in the experiments.

* Editor's Note.—For article on interpretation of pH curves, see Miscellany, page 475.

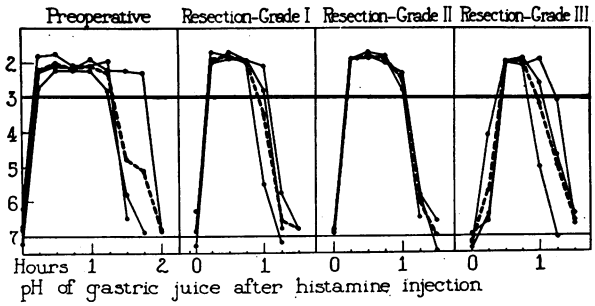

Fig. 3.—Chart illustrating the effect of graduated multiple resection of the pylorus on the hydrogen ion concentration of gastric content according to repeated fractional gastric analysis employing the standard dose of histamin. Note that the H ion concentration is normal after all grades of resection.

Subsequent to resection of the pyloric sphincter the acid values of gastric content were not reduced. Following removal of the distal half of the pylorus the acid values in the stomach content were slightly reduced. Removal of the entire pylorus was followed by a marked reduction in hydrogen ion concentration and total acid, and free hydrochloric acid did not appear. These observations were made when the test-meal was used in gastric analysis. A noteworthy difference in the results of gastric analysis was observed following the injection of histamin as a gastric secretory stimulant. After administration of this drug, reductions corresponding to the grades of resection were not noted (Fig. 3). A more striking difference, however, was that after Grade 3 resection of the entire pylorus, free hydrochloric acid, by contrast, was present. The latter observation indicates that despite the absence of the pylorus, the fundus, under appropriate conditions, is capable of secreting gastric juice which contains free hydrochloric acid. This difference in the presence or absence of free hydrochloric acid in gastric content, according to the kind of secretory stimulant applied, appears to have an important bearing on the mechanisms of secretion and of neutralization of gastric juice.

In roentgenologic observations on the emptying rate of the stomach following graduated multiple resections of the pylorus, interesting results also were observed. Following resection of portions of the pylorus, the emptying rate was reduced below the preoperative emptying time, regardless of the grade of resection. The rate, however, was not reduced increasingly for each grade of resection. Absence of the pyloric sphincter, therefore, rather than the increase in diameter of the pyloric outlet, seems to be responsible for the result observed.

PYLORIC RESECTION WITH BILLROTH GASTRODUODENOSTOMY AND GASTROJEJUNOSTOMY

In the four animals in which resection of the pylorus with Billroth I gastroduodenostomy and Billroth II gastrojejunostomy were performed, comparable results with respect to gastric secretion and motility were observed, with one exception: the emptying rate of the stomach was not reduced after Billroth II gastrojejunostomy (Fig. 4).

PAVLOV FUNDUS POUCH

In the preceding paragraphs it has been shown that there is a discrepancy in the amount of free hydrochloric acid present in the content of the pylorectomized stomach following the use of two types of gastric secretory stimuli. As a means of investigating this discrepancy, Pavlov pouches were constructed in the fundus of the pylorectomized stomach of five dogs, so that simultaneous fractional analysis of pure fundus juice and of mixed gastric content could be made. On comparison it was noted that the acid values of the mixed gastric content were low, and free hydrochloric acid was not present. The juice of the fundus pouch, on the other hand, possessed acid values which were normal, and free hydrochloric acid was present (Fig. 5). The fundus, therefore, actually secreted gastric juice having acid values which were normal. Following injection of histamin, the acid values of the gastric content, likewise, were lower than those of the pouch juice. From these observations it may be inferred that after resection of the pylorus there is a relative increase of buffer and neutralizing values in the gastric content.

BILATERAL TRANSTHORACIC VAGOTOMY

Elimination of the gastric phase of gastric secretion by pylorectomy having disclosed that the fundus pouch secreted gastric juice having normal acid values, the question naturally arose regarding the relative importance of the cephalic phase of secretion in the secretory activity of the fundus. Bilateral transthoracic vagotomy was used to eliminate the cephalic phase of gastric secretion in three pylorectomized dogs. Following this

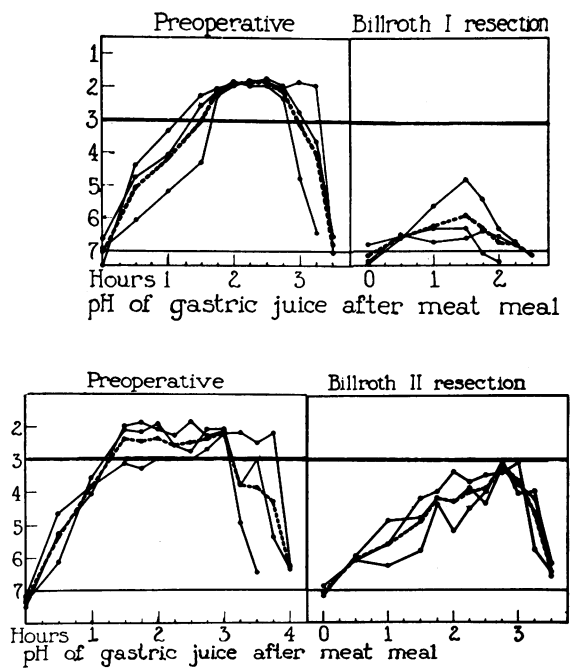

Fig. 4.—Charts illustrating the comparative effects of resection of the pylorus with Billroth I gastroduodenostomy and Billroth II gastrojejunostomy. Note that the H ion concentration is higher after Billroth II than after Billroth I, but that free hydrochloric acid is not present after either Billroth I or II.

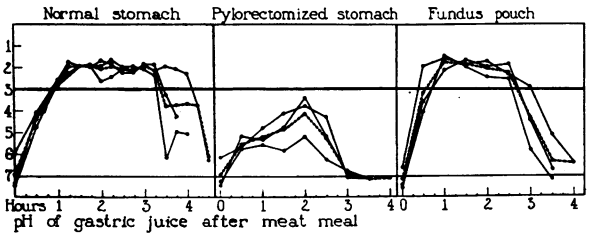

Fig. 5.—Charts illustrating the comparative concentration of H ions in the mixed gastric content and the pure fundus pouch juice of the pylorectomized stomach. Note that while the acid values of the pure pouch juice were normal, those of the mixed gastric content were low, and that free hydrochloric acid was not present, i. e., H ions below 3.

procedure, gastric juice with extremely low acid values was secreted on ingestion of food (Fig. 6). This observation indicates that, following pylorectomy, the cephalic phase of secretion is of major importance to the secretory activity of the remaining fundus.

ROUX JEJUNOJEJUNOSTOMY

The foregoing comparison of pure fundus pouch juice with mixed fundus content suggested that resection of the pylorus was followed by a relative increase in the amount of buffer substances present in the content of the stomach. As a means of determining the extent to which duodenal juices contribute to this apparent increase in buffer substances, these juices were excluded from the stomach by means of the Roux jejunojejunostomy performed upon three dogs, which had previously been pylorectomized with Polya gastrojejunal anastomosis. After exclusion of the duodenal juices from the stomach by the Roux operation, slightly higher acid values were present in the gastric content (Fig. 6). This indicates that the duodenal juices which enter the stomach normally or after resection of the pylorus possess a slight degree of buffer value and neutralizing power.

NEUTRALIZING EFFECT OF FOOD

The extent to which duodenal juices neutralize gastric juice having been ascertained, there remained to be determined the buffer value and neutralizing power of the food used in the analysis of the content of the pylorectomized stomach. In this investigation, a comparison was made between the results obtained from the standard meal and those secured when a meal containing half the standard quantity of the same ingredients was used. Higher acid values were obtained on employment of the half-quantity meal (Fig. 7). This result reveals that meals of ordinary size may

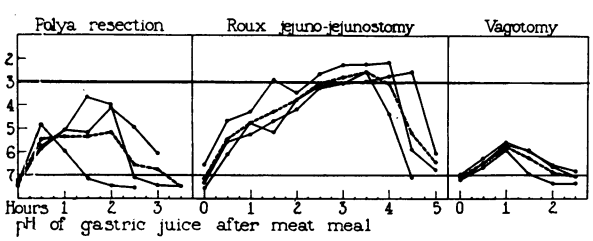

Fig. 6.—Charts illustrating the effects of the Roux jejunojejunostomy and of bilateral vagotomy on the acid values of the content of the pylorectomized stomach. Note that the acid values are higher after the Roux operation and lower after vagotomy.

contain sufficient protein to neutralize all of the hydrochloric acid the fundus is capable of secreting.

SUMMARY

A comprehensive study of the effects of resection of the pylorus on the secretory and motor functions of the stomach is reported herein. The manner of approach is different from that of any clinical or experimental investigation reported previously. The method is based on the application of certain standard and specially devised surgical operations to the normal stomachs of dogs. The physiologic effects of the operations are observed by gastric analysis and by roentgenologic examination.

A number of significant facts were observed in this study. Contrary to prevailing opinion, and despite the fact that the pyloric sphincter regulates the emptying of the stomach and the admission of duodenal juices into it, resection of the sphincter, combined with Polya gastrojejunostomy, does not lower the acidity of gastric content nor hasten emptying of the stomach. Graduated multiple resections of the pylorus confirmed the prevailing belief that the pylorus is essential to physiologically normal gastric secretory function. A roughly quantitative relation between the amount of pylorus present and the efficiency of secretion is suggested. The fact that widening of the outlet of the stomach does not shorten its emptying time also is contrary to the general conception.

The most important contribution resulting from this study refers to the apparent and real secretory functions of the pylorectomized stomach. The use of histamin and the Pavlov pouch disclose that the fundus, after removal of the pylorus, continues to secrete gastric juice having normal acid values. The most important factor in the secretion of gastric juice by the pylorectomized stomach is the cephalic phase of secretion as revealed by the performance of vagotomy. Achlorhydria occurring after pylorectomy is apparent only, and is the result of neutralization by the duodenal juices and the food. In the past the importance of the duodenal juices in this respect has been overemphasized, whereas the neutralizing capacity of the food has not been stressed sufficiently.

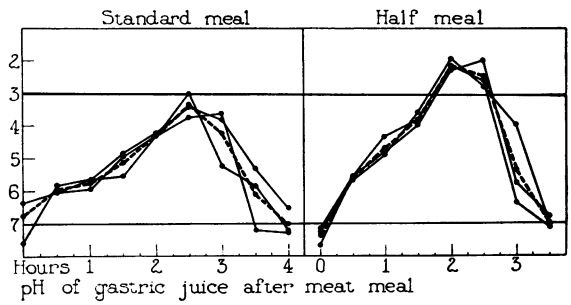

Fig. 7.—Charts illustrating the comparative effects of the use of the standard and the half-standard meal in gastric analysis following resection of the pylorus. Note that the acid values are higher when the half-standard meal is used and that free hydrochloric acid is present.

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